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CHARACTERIZING AND VALUE-ADDED PROCESSING OF LOW-QUALITY GRAINS. A SPECIAL RESEARCH AND TECHNOLOGY TRANSFER PROJECT

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Final Report

CHARACTERIZATION AND VALUE-ADDED PROCESSSING OF LOW QUALITY GRAINS – A SPECIAL RESEARCH AND TECHNOLOFY TRANSFER PROJECT

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ADF Agri-Value Program

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Summary

The grain harvest of 2002 was of poor quantity and quality. Characterization of quality and improvements of its nutritional quality were explored in a research program with five studies: (1) barley quality; (2) wheat quality; (3) barley processing; (4) wheat processing; (5) wheat enzyme. Study 1 was entirely funded by the ADF Agri-Value program and is described in this report, together with summaries of studies 3 and 5. Barley nutritional quality measured as digestible energy (DE) ranged 40% and was predicted best by acid detergent fibre (ADF). The range in quality in the 2002-crop was larger than ever measured before.

Technical Report

Background

The harvest of 2002 was of poor quantity and quality. The quality of this grain must be characterized and manners to improve its nutritional quality should be explored. A special research and technology transfer project was conducted for the agricultural industry to deal with this urgent problem and the project in its entity is almost completed. The overall scope of the project is product development, because the nutritional value of the unique 2002-harvest for wheat and barley will be explored.

Barley is one of the main ingredients in Western Canadian swine diets. But, the nutritional value of barley is highly variable due to differences in cultivar, growing and storage conditions, and the degree of drying (van Barneveld, 1999). To manage grain quality variation, the feed grain nutrient with the greatest impact on diet cost and/or animal performance should be measured. In the case of barley this is digestible energy (DE). Western Canadian barley DE content can vary by as much as 637 kcal/kg (18%; 2,984 to 3,621 kcal/kg DM) due to differences in the grain's energy digestibility (Anderson and Bell, 1983; Fairbairn et al., 1999).

Currently, the Canadian grading system assesses barley quality by measuring volume weight (normal, 48 lb/bu; poor, < 46 lb/bu), sprouting and(or) frost damage. Better indicators of barley quality and DE content, such as acid detergent fibre (ADF), have been suggested (Fairbairn et al., 1999). These indicators provide a good measure of barley's DE content, which in turn allows for a more accurate diet formulation. However, the nutritional value of very low quality barley (< 2,984 kcal DE/kg DM) has not been assessed adequately, and the existing prediction equations do not reflect the nutritional value of barley such as this.

Project objectives

Characterization of quality and improvements of its nutritional quality were explored in a research program with five studies: (1) barley quality; (2) wheat quality; (3) barley processing; (4) wheat processing; (5) wheat enzyme. Overall project objectives were:

1. To characterize the digestible energy (DE) content and chemical characteristics of the low quality wheat and barley crop of the 2002 harvest.
2. To increase the DE content of low quality wheat and barley by value-added processing, specifically by reducing particle size.
3. To increase the nutritional value of low quality wheat by adding supplemental enzymes to diets.

4. To express the improvement in nutritional value as increased $ value per tonne of low quality feed grain.

The **specific objectives** for the study described in this report were:

1. To characterize the digestible energy (DE) content and chemical characteristics of the low quality barley crop of the 2002 harvest.
2. To define equations to predict the DE content of low quality barley using the grain's physical and chemical characteristics.
3. To compare the results of key chemical characteristics between laboratories to ensure the prediction equations are usable by producers.

Scientific summary

This experiment was conducted to measure the chemical and physical characteristics of very low quality barley, and to develop a practical method, usable by producers, to accurately estimate the DE content of individual barley samples. Twenty-one barley samples were collected from the 2002-harvest in Saskatchewan to obtain a broad range of quality. This harvest poses a particularly acute challenge to the swine industry in Western Canada due to grain supply shortfalls and poor quality. But the wide variation in quality also provided an opportunity to better understand nutritional variation. Six measurements were collected on each barley sample using 63 crossbred barrows, in an apparent total tract digestibility study. The barrows, average body weight of 33.1 kg, were housed in individual pens. Five-day fecal collection periods followed 5-d diet acclimation periods. Nutritional characteristics of the barley samples were qualified (expressed on DM-basis), and used to estimate their DE content using PSC prediction equations. Overall, content of barley moisture averaged 13.8 ± 1.6% (range: 10.2 to 17.9%), CP averaged 12.6 ± 1.4% (range: 8.8 to 15.4%), ADF averaged 7.4 ± 1.5% (range: 5.7 to 12.1%), NDF averaged 20.5 ± 3.4% (range: 16.2 to 32.0%), ether extract averaged 2.3 ± 0.3% (range: 1.8 to 3.0%), ash averaged 2.8 ± 0.6% (range: 2.2 to 4.7%), lignin averaged 1.3 ± 0.4% (range: 0.9 to 2.7%), and measured DE content averaged 2,969 ± 264 kcal kg^{-1} DM (range: 2,018 to 3,291). The DE content of a specific barley samples could be predicted best with a single predictor using acid-detergent fibre (ADF).

Materials and methods

Selection and preparation of the barley samples

Twenty-one barley samples (~130 kg) were collected, based on density and harvesting condition, from the 2002 harvest in Saskatchewan. Collection of 20 of the samples was co-ordinated by Big Sky Farms Inc., the other barley sample was provided by Dr. Beltranena (Prairie Swine Centre). The Canadian Grain Commission (Saskatoon, SK, Canada) measured dockage and field and cleaned test weight (kg/hL) on each barley sample. The 21 barley samples were individually ground through a Jacobsen hammermill (Model #160-D, Jacobson Machine works, Minneapolis, MN) using a 1/8" screen at the University of Saskatchewan, Department of Animal and Poultry Science feed mixing room. A 2.5-kg unground sample of the 21 types of grain was collected in a plastic bag by removing ~0.5 kg of grain from each 25-kg bag of unground barley. About a 100 g sample of each unground grain sample was sent to a commercial lab (NorWest Labs, Lethbridge, AB) for protein, moisture, ADF and NDF analysis. A similar amount of barley was sent to the University of Saskatchewan for protein, moisture, ADF, NDF, ash, ether extract, and lignin analysis, and to the Degussa Corporation, Germany for protein and amino acid analysis.

Animal and diets

Twenty-one mash diets were formulated to contain 96.4% of each barley sample, 3.2% minerals and vitamins, and 0.4% chromic oxide (Table 1). The test diets were individually mixed and bagged in 125-kg batches at the University of Saskatchewan, Department of Animal and Poultry Science feed mixing room. One tonne of a 96% barley mash acclimation diet (Table 1) was mixed and bagged at the Co-Op feed mill, Saskatoon, SK. Barley was assumed to be the only source of energy in the diet; the slight contribution of energy from the vitamin and mineral premixes was assumed to be negligible. Vitamins and minerals were supplied at levels formulated to exceed the requirements of 20 to 50-kg growing pigs, as defined by NRC (1998).

The animal protocol was approved by the University of Saskatchewan's University Committee on Animal Care and supply, and followed principles established by the Canadian Council on Animal Care.

The 21 barley samples were evaluated for DE content in grower pigs in a two-period crossover design for a total of 126 observations (six observations per barley sample). Sixty-three crossbred barrows (C-22 dams x Line-65 sires, Pig Improvement Canada, Acme, AB, Canada) with an average initial body weight of 33.1 ± 0.4 kg and age of 70.8 ± 0.4 d were assigned to one of three groups of 21 barrows within one room. Each pig within a group was assigned randomly to one of the 21 experimental test diets. To randomize the treatments within a group, pigs in a group were free to choose from the assigned pens. Pigs were fed different test diets in the first and second periods. To reduce variation among treatments, at the diet switch the pig in each of the three groups eating the same diet in period one received different diets from each other in period two. At least one extra pig was included in each group, to be used if a pig in the group was removed from test. This pig was fed as the experimental pigs during the acclimation period.

Pigs were housed in individual pens in an environmentally controlled room, for a period of 30 d. Room temperature was maintained at the thermo-neutral zone of 20 to 40 kg pigs (~21°C), to preclude any adverse effects on feed intake. The lighting schedule was set to 12 hr light and 12 hr dark. All pigs were weighed at the start of the experiment, at each diet change, and after completion of the experiment. Pigs received an equal amount of feed twice daily, at 0830 and 1530, and had free access to water via a nipple drinker. Because the level of feed intake affects digestibility, feed intake was limited to 3.0 x maintenance (NRC, 1998), assuming the standard diet contained 3,500 kcal DE/kg and 22.3% CP, and the barley test diets contained 2,950 kcal DE/kg and 10.1% CP. Pigs within the same group were offered the same feed level, based on the average body weight of pigs in that group. Feed level was altered when the pigs were weighed. Pigs with a low feed disappearance were removed from the experiment.

Pigs were transferred gradually from the standard wheat/soybean diet to the 96%-barley mash acclimation diet (Table 1) during a 10-d acclimation period. Pigs were fed a 100% standard diet on d 1, 75% standard and 25% acclimation diet on d 2, 50% standard and 50% acclimation diet on d 3, 25% standard and 75% acclimation diet on d 4, and 100% acclimation diet on d 5 to 10. Pigs were then fed their first assigned experimental test diet for a 10-d period, immediately followed by their second assigned experimental test diet for further 10-d period. For each experimental diet, pigs were given a 5-d period to adapt to their respective diets followed by a 5-d period in which daily fecal grab samples and feed samples were collected.

On each fecal collection day the floor of each pen was scraped clean of feces before the morning feeding. Feces were then gathered from the floor of the pen throughout the day, using the grab method, until 1530. Daily collections for each pig and period were pooled for each diet,

in an individual plastic bag, stored at –20°C, and later thawed, homogenized in a Hobart mixer (model D-300-T, Hobart Corp., Troy, OH), and aliquoted into two 200 g sub-samples individually stored, in plastic bags, at –20°C. One sample was freeze-dried. During the collection period, about a 100 g/d feed sample was removed from the feedbag, and stored at –20°C to be sub-sampled and pooled for later analysis. The feed and freeze-dried fecal samples were later analysed for dry matter, gross energy, and chromic oxide.

Analytical methods

The barley grain, feed, and fecal samples was analyzed for dry matter using method 934.01 (AOAC, 1990) and for energy using adiabatic bomb calorimetry (Parr Adiabatic Calorimeter, model 1200, Parr Instruments, Moline, IL). Chromic oxide in feed and feces was determined by the method of Fenton and Fenton (1979).

The following analyses were conducted on the barley grain samples: nitrogen was analyzed using the FP-428 Nitrogen Determinator, System: 601-700-900 (LECO Corporation, St. Joseph, MI), amino acids were determined by HPLC, ether extract was determined using method 7.061 (AOAC, 1984), ash content with method 942.05 (AOAC, 1990), ADF and acid detergent lignin with method 973.18 (AOAC, 1990), NDF with the method of Van Soest et al. (1991) with pre-digestion of 50 µL of thermostable alpha-amylase (A-3306, Sigma Chemical Co., St Louis, MO) per sample to enhance starch precipitation. A Labconco crude fibre extractor (model 30011, Labconco Corp., Kansas City, MO) was used for ADF and NDF determination.

Calculations and statistical analyses

All digestibility coefficients were measured on the 21 feed samples, and later converted to reflect the digestibility of the individual barley samples. Apparent energy digestibility was calculated following the indicator method, using chromic oxide as the indicator, according to the direct method (GE barley sample (DM basis) * apparent total-tract energy digestibility of diet). Barley was assumed to be the only energy-contributing ingredient.

This experiment was considered a completely randomized design. The individual animal and the grain samples were considered the experimental unit for analysis of differences in apparent energy digestibility, and other grain characteristics. Variables were analyzed using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC). The statistical model included effects of dietary treatment and group. To relate particular grain characteristics with DE content, correlation analysis was performed. Regression equations to prediction the DE of low quality barley, based on the grain's chemical and physical characteristics, were conducted using the Stepwise procedure of SAS (SAS Inst., Inc., Cary, NC).

Results and discussion

The chemical and physical characteristics of the 21 barley samples tested in this experiment were highly variable (Table 2). Gross energy varied very little (CV of 0.7%) and the two extreme gross energy values only varied by 2.8%. Thus, most of the difference in barley grain digestible energy content was due to differences in energy digestibility. Apparent digestibility coefficients for energy in the barley grain samples measured varied from 45.2 to 75.4 ± 0.8%. Similarly, the extreme values for all the grain chemical characteristics measured, except gross energy, varied by 33 to 68%, and had CVs of 8.5 to 29.8%.

All the measured physical characteristics of the barley were also highly variable. The two extreme values in test weigh varied by about a 50% (difference of 34.6 kg/hL field, and 31.7 kg/hL cleaned), and those for moisture varied by 43% (difference of 7.7%). Notable differences

between the official test weight, determined on cleaned and sieved samples, and those conducted on uncleaned (field) samples were also evident, due to a wide variation in the quantity of dockage within the samples.

Comparison of values measured at different laboratories

Table 3 compares three chemical characteristics of barley (CP, ADF, and NDF) measured in different laboratories (University of Saskatchewan, Norwest Labs, Lethbridge, and Degussa Corp., Germany). Grain CP content in all three laboratories was highly correlated ($r > 0.96$; $P < 0.001$), but CP measured at the University of Saskatchewan was about one percentage unit lower than that measured in the other two labs (Figure 1). The values for ADF ($r = 0.87$) and NDF ($r = 0.76$) measured at the University of Saskatchewan and Norwest Labs were also well ($P < 0.001$) correlated. Barley ADF levels measured at Norwest labs were about a percentage unit lower and NDF levels were three to seven percentage units higher than those measured at the University of Saskatchewan (Figure 1). The NDF values measured by the University of Alberta were within the range of previously measured levels (Table 4), but one sample measured by Norwest labs was three percentage units higher than those previously measured (35.1 vs 31.9%). This indicates that there are still some control problems with this analysis across laboratories. Regression equations converting the University of Saskatchewan results to those for Norwest labs and Degussa are listed in Figure 1.

DE prediction equations for low quality barley

The three groups of barrows used to measured apparent energy digestibility in the 21 barley samples had an average age of 68.2, 74.7, and 69.4 ± 0.4 d, and an average weight of 34.4, 32.0, and 33.1 ± 0.4 kg, at the start of the first test period. These three groups of barrows grew at 454, 539, and 399 g/d in the 10-d acclimation period at the 3 x maintenance feeding level.

Figure 2 illustrates the relationship, in the 21 barley grain samples, between the DE measured in our experiment with gross energy, and the DE calculated by Norwest labs and by using the equation of Fairbairn et al. (1999). The DE content calculated using Fairbairn's equation was higher (averaged 3,152 ± 156 kcal/kg DM) than the measured DE content, and showed less variation (CV = 5.0 vs 8.9%). But this equation better represented the measured DE content than the other estimates used. However, the DE content of very low quality barley was still not adequately estimated. For example, the equation of Fairbairn et al. (1999) predicted a 33% higher DE content for the barley sample with the lowest measured DE content (2,674 vs 2,018 kcal/ Kg DM).

The measured DE value of the 21 barley samples averaged 2,969 ± 264 kcal/kg DM, and showed a greater variation than any of the other calculated values, or the measured gross energy value (averaged 4,392 ± 31 kcal/kg DM). The DE content of the same samples calculated by Norwest labs were closer in value to the measured DE content (averaged 3,721 ± 75 kcal/kg DM) than gross energy, and showed more variation (CV = 0.7 vs 2.0%).

The correlations coefficients for gross energy, and the calculated (Norwest Labs) and measured digestible energy content of the barley grain against measured physical and chemical characteristics of the grain are listed in Table 5. Gross energy was fairly poorly correlated with most of the characteristics measured. Lignin ($r = 0.53$), test weight and CP ($r > -0.46$), lysine ($r = 0.60$), and methionine and threonine ($r > 0.45$) were related ($P < 0.05$) to grain gross energy. Stronger correlations coefficients were associated with grain DE content and the physical and chemical characteristics measured. The measures of grain fibre content, ADF ($r > -0.86$), NDF ($r > -0.79$) and lignin ($r > -0.67$), were strongly and negatively related ($P < 0.001$) to barley DE

content. Test weight was also strongly related ($r > 0.76$) to barley DE content. But the measured DE content of the barley was not related with the gross energy in the grain.

The gross energy, CP, ether extract, and ash values for barley were in the range of previously recorded values (Table 4). The lowest ADF values were consistent with those measured by others, but the highest ADF values measured at both the University of Saskatchewan and Norwest labs were one to two percentage units higher than previously recorded levels (10.2%). Thus, it appears that some of our barley samples were indeed very different from those previously measured. Similarly, field test weights lower than 44.7 kg/hL have not been recorded in previous experiments; one of our samples had a field test weight of 31.5 kg/hL. Furthermore, we observed lower apparent energy digestibility and DE values than previously recorded in barley (Table 4). Previously the lowest barley DE value recorded was 2,984 kcal/kg DM and the next lowest samples were over 3,000 kcal DE/kg DM (Fairbairn et al., 1999). In our experiment, 7 of the 21 barley samples had a DE content equal or lower than 2,984 kcal/kg DM, and another 3 samples had a DE content less than 3,000 kcal/kg DM. The highest DE content in our data set was 3,291 kcal/kg DM.

Table 6 and 7 list the prediction equations for barley DE content formulated using the physical and chemical characteristics of the 21 barley samples in our experiment. The equations in Table 6 use the chemical characteristics measured in the University of Saskatchewan laboratory, and those in Table 7 use the chemical characteristics measured in Norwest Labs. In both sets of equations ADF was the best single variable model, but the equation formulated from the Chemical characteristics measured in Norwest labs explained slightly more of the variability in grain DE content (81 vs 76%). In agreement, ADF also was the best single variable predicting barley DE content in the experiment of Fairbairn et al. (1999; $R^2 = 0.85$). Our equations explained less of the variability in barley DE content likely because some of our barley samples were of lower quality than others previously tested.

The best three-variable equations, using characteristics measured in Norwest labs, explained 90% of the variability in barley DE content and included ADF, NDF, and CP. Similar equations formulated using barley characteristics measured in the University if Saskatchewan lab explained 84% of the variability in barley DE content and included test weight (kg/hL), ADF and NDF, or ADF, NDF, and lignin.

Conclusions

The nutritional quality of barley measured as digestible energy (DE) content ranged 40% for the 2002-crop. This range in quality in the 2002-crop was larger than ever measured before.

The range in DE content was predicted best by acid detergent fibre (ADF) using the equation: DE (kcal/kg DM) = 4,032 (± 121) – 156.7 (± 17.4) x ADF (%DM) $R^2 = 0.81$; ADF and DM analyses were completed at Norwest Labs.

The results of chemical analyses differ among laboratories. Prediction equations are only valid for chemical analyses completed within a laboratory and cannot be extrapolated between laboratories.

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Personnel

Dr. Emma J. Clowes was at Prairie Swine Centre as a Visiting Scholar during the animal component of the project while being employed at Alberta Agriculture, Food and Rural Development as a Pork Systems Specialist. Danielle Bauche was working on the project as an animal technician. Gemunu Widyaratne was working on the project as a laboratory technician. Ryan Mohr worked on the project to collect barley samples.

Equipment

Equipment was not purchased.

Project Developed Materials

Deliverables for the entire project include the following.

Research reports

Clowes, E.J., R.T. Zijlstra. 2003. Grain quality. Centred on Swine. Fall 2003 newsletter. Volume 10, Number 3. Prairie Swine Centre Inc., Saskatoon, SK. (submitted).

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Zijlstra, R.T. 2003. Variation in feed quality of barley for pigs. 3rd Canadian Barley Symposium, Barley Development Council. Red Deer, AB. June 19-20.

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Zijlstra, R.T. 2002. Addressing variation in ingredient quality: what to do when feed quality declines. PSCI-FeedRite meetings. November 26, Swift Current, SK; November 27, Saskatoon, SK.

Project photos

Photos were not taken.

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Table 1. Composition of experimental and acclimation diets (%, on an as-fed basis)

Ingredients	Acclimation diet	Experimental diet
Barley ordinary sample	96.76	-
Experimental test barley	-	96.36
Limestone	1.03	1.03
Dicalcium phosphate	0.81	0.81
Vitamin mix[a]	0.50	0.50
Mineral mix[b]	0.50	0.50
Salt	0.40	0.40
Chromic oxide	-	0.40
Total	100.00	100.00
Estimated nutrient levels		
DE, kcal/kg	2,950	2,950
CP, %	10.1	10.1

[a] Provided the following per kilogram of diet: vitamin A, 8,250 IU; vitamin D3, 825 IU; vitamin E, 40 IU; menadione, 4 mg; thiamine, 1 mg; riboflavin, 5 mg; d-pantothenic acid, 15 mg; niacin, 35 mg; vitamin B12, 0.025 mg; d0biotin, 0.2 mg; folic acid, 2 mg.

[b] Provided the following per kilogram of diet: Zn, 100 mg; Fe, 80 mg; Mn, 25 mg; Cu, 50 mg; I, 0.5 mg; Se, 0.1 mg.

Table 2. Chemical and physical characteristics of the 21 barley grain samples

	Mean	SD	CV	Lowest	Highest
Physical Characteristics					
Field test weight, kg/hL	55.0	7.2	13.1	31.5	66.1
Clean test weight, kg/hL	56.1	6.6	11.7	35.1	66.8
Dockage, %	1.72	1.12	65.2	0.26	4.10
Moisture, %	13.8	1.60	11.5	10.2	17.9
Chemical characteristics on a DM basis[a]					
Gross energy, kcal/kg	4392	30.8	0.7	4337	4462
DE, kcal/kg - measured	2969	264	8.9	2018	3291
CP, %	12.6	1.4	11.2	8.8	15.4
CP[a], %	13.7	1.4	10.5	10.0	16.4
CP[b], %	13.9	1.4	10.4	10.3	16.4
ADF, %	7.42	1.53	20.6	5.70	12.07
ADF[a], %	6.79	1.52	22.3	4.50	11.40
NDF, %	20.5	3.37	16.5	16.2	32.0
NDF[a], %	26.2	2.90	11.0	21.9	35.1
Ether Extract, %	2.31	0.31	13.4	1.76	2.98
Ash, %	2.82	0.56	19.9	2.16	4.66
Lignin, %	1.29	0.38	29.8	0.86	2.67
Lysine[b], %	0.52	0.044	8.5	0.38	0.57
Methionine[b], %	0.24	0.021	8.8	0.18	0.27
Cystine & Methionine[b], %	0.54	0.051	9.4	0.40	0.62
Threonine[b], %	0.48	0.043	8.9	0.35	0.54

All chemical analyses were conducted at the University of Saskatchewan unless otherwise indicated.

[a] Chemical analysis conducted by Norwest Labs, Lethbridge

[b] Chemical analysis conducted by Degussa AG, Germany

Table 3. Pearson correlation coefficients for grain chemical characteristics among laboratories

	Crude Protein			Acid Detergent Fibre		Neutral Detergent Fibre	
	U of S	**Norwest**	**Degussa**	**U of S**	**Norwest**	**U of S**	**Norwest**
Crude Protein							
U of S	1.000	0.975 < 0.001	0.967 < 0.001	-0.011 NS	0.144 NS	-0.191 NS	0.187 NS
Norwest	0.975 < 0.001	1.000	0.965 < 0.001	-0.036 NS	0.098 NS	-0.218 NS	0.155 NS
Degussa	0.967 < 0.001	0.965 < 0.001	1.000	0.078 NS	0.204 NS	-0.141 NS	0.218 NS
Acid Detergent Fibre							
U of S	-0.011 NS	-0.036 NS	0.078 NS	1.000	0.870 P < 0.001	0.727 P < 0.001	0.719 P < 0.001
Norwest	0.144 NS	0.098 NS	0.204 NS	0.871 P < 0.001	1.000	0.701 P < 0.001	0.793 P < 0.001
Neutral Detergent Fibre							
U of S	-0.191 NS	-0.218 NS	-0.141 NS	0.727 P < 0.001	0.701 P < 0.001	1.000	0.757 P < 0.001
Norwest	0.187 NS	0.155 NS	0.218 NS	0.719 P < 0.001	0.793 P < 0.001	0.757 P < 0.001	1.000

Table 4. Range of previously published hulled barley grain characteristics

Characteristic	Minimum	Maximum	References[a]
Bulk weight, kg/hL (as fed)	44.7	67.3	1, 2, 3, 6, 7, 8, 12
Gross energy, Mcal/ kg DM	4.154	4.735	1, 2, 4, 5, 6, 7, 8, 11,13
Apparent energy digestibility[b], %	57.6	82.1	1, 2, 8, 11, 12, 13
Digestible energy[b], Mcal/kg DM	2.80	3.59	1, 2, 8, 11, 13
Crude protein, %	8.34	17.2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
ADF, %	4.96	10.18	7, 8, 11
NDF, %	16.3	31.9	8, 9, 11
Ether extract, %	1.4	3.2	3, 5, 6, 7, 8, 11
Lignin, %	0.9	1.7	6, 8, 11
Ash	2.0	5.0	3, 5, 6, 7, 8, 12
Lysine, %	0.31	0.51	5, 9, 10

References: 1 = Anderson & Bell, 1983a; 2 = Anderson & Bell, 1983a ; 3 = Bhatty et al., 1974; 4 = Bhatty et al., 1975; 5 = Bhatty et al., 1979; 6 = Christison & Bell, 1975; 7 = Coates et al., 1977; 8 = Fairbairn et al., 1999; 9 = Fan & Sauer, 2002; 10 = Fontaine et al., 2002; 11 = Noblet et al., 1993; 12 = Plett & Aherne, 1987, 13 = A.R. Barr & R.J. van Barneveld published in van Barneveld, 1999

Digestible energy and apparent energy digestibility measured in pigs only

Table 5. Pearson Correlation Coefficients for grain chemical characteristics among laboratories

	Gross Energy	Digestible Energy, U of S	Digestible Energy, Norwest
Digestible energy - measured	-0.330 NS	1.000	0.895 P < 0.001
Digestible energy – calculated by Norwest	-0.348 NS	0.895 P < 0.001	1.000
Crude protein – U of S	0.464 P < 0.05	0.077 NS	-0.163 NS
Crude protein – Norwest	0.319 0.1586	0.138 NS	-0.116 NS
Crude protein – Degussa	0.481 P < 0.05	0.043 NS	-0.221 NS
Acid detergent Fibre – U of S	0.314 NS	-0.864 P < 0.001	-0.858 P < 0.001
Acid detergent Fibre – Norwest	0.349 0.1214	-0.901 P < 0.001	-0.999 P < 0.001
Neutral detergent Fibre – U of S	0.131 NS	-0.797 P < 0.001	-0.692 P < 0.001
Neutral detergent Fibre – Norwest	0.314 NS	-0.820 P < 0.001	-0.789 P < 0.001
Ether Extract	0.130 NS	0.009 NS	-0.030 NS
Ash	-0.235 NS	-0.244 NS	-0.444 P < 0.05
Lignin	0.526 P < 0.05	-0.678 P < 0.001	-0.484 P < 0.05
Test weight - field	-0.483 P < 0.05	0.793 P < 0.001	0.854 P < 0.001
Test weight - clean	-0.462 P < 0.05	0.765 P < 0.001	0.819 P < 0.001
Dockage	0.046 NS	-0.145 NS	-0.316 NS
Methionine, %	0.445 P < 0.05	0.213 NS	-0.072 NS
Cysteine, %	0.334 0.1387	0.449 P < 0.05	0.172 NS
Lysine, %	0.600 P < 0.01	-0.317 0.1617	-0.556 P < 0.01
Threonine, %	0.451 P < 0.05	-0.024 NS	-0.317 0.1621

Table 6. Prediction equations of DE (kcal/kg DM) based on chemical (measured at the University of Saskatchewan) and physical variables of the barley samples[a]

No.	Equation	R^2
1	DE = 4,076 (± 151) – 149.2 (± 19.9) x ADF	0.76
2	DE = 4,318 (± 169) – 104.2 (± 26.1) x ADF – 28.1 (± 11.8) x NDF	0.81
3	DE = 2,757 (± 409) + 19.5 (± 4.9) x test wt – 43.0 (± 9.5) x NDF	0.81
4	DE = 3,415 (± 544) + 11.4 (± 6.6) x test wt – 60.8 (± 35.2) x ADF – 31.0 (± 11.5) x NDF	0.84
5	DE = 4,316 (± 158) – 89.6 (± 25.5) x ADF – 23.4 (± 11.3) x NDF – 158 (± 82.6) x lignin	0.84

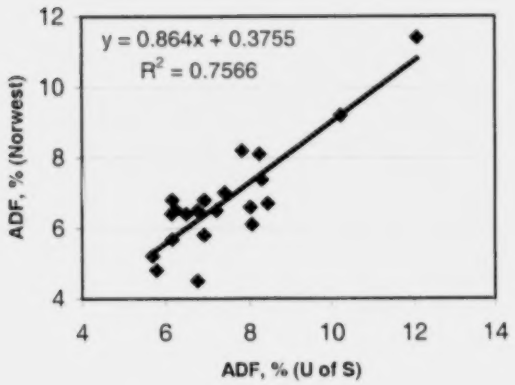
[a] All grain characteristics, other than test wt (cleaned test weight, kg/hL), were measured on a DM basis. Test wt was measured "as is".

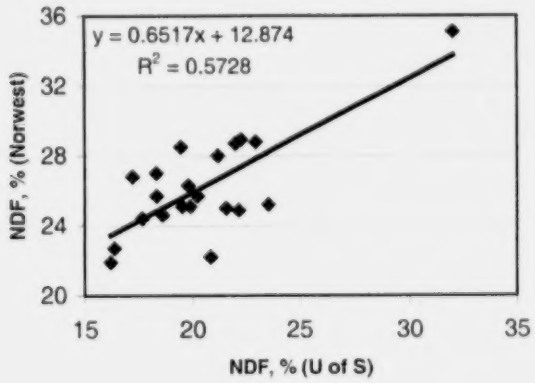
Table 7. Prediction equations of DE (kcal/kg DM) based on the chemical (measured at Norwest labs) and physical variables of the barley samples[a]

No.	Equation	R^2
1	DE = 4,032 (± 121) – 156.7 (± 17.4) x ADF	0.81
2	DE = 3,482 (± 237) – 160.5 (± 15.3) x ADF + 42.3 (± 16.3) x CP	0.86
3	DE = 3,909 (± 256) – 114.3 (± 21.4) x ADF – 30.8 (± 11.3) x NDF + 47.2 (± 14.1) x CP	0.90
4	DE = 3,708 (± 516) + 2.56 (± 5.67) x test wt – 104.4 (± 30.9) x ADF – 31.2 (± 11.6) x NDF + 47.2 (± 14.4) x CP	0.91

a All grain characteristics, other than test wt (cleaned test weight, kg/hL), were measured on a DM basis. Test wt was measured "as is".

Figure 1. Comparison of the CP, ADF, and NDF values (on a DM basis) measured at the University of Saskatchewan (U of S), Degussa, and Norwest Labs





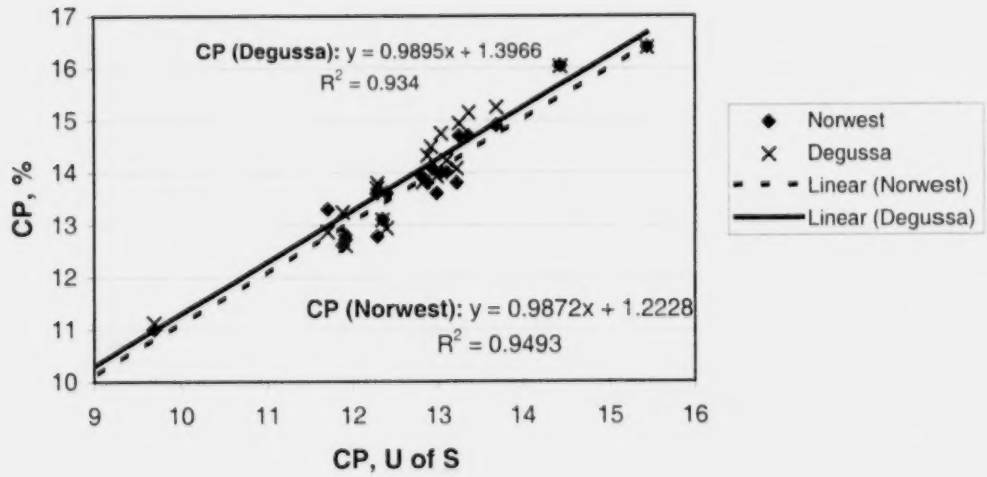


Figure 2. Gross energy (GE) and measured and calculated digestible energy (DE) in the 21 barley samples

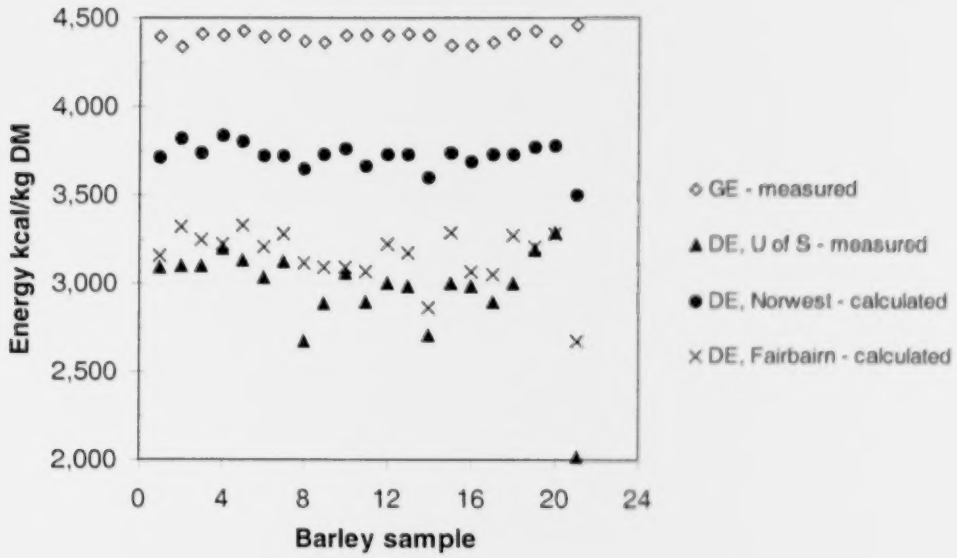


Table 8. Appendix: Physical and chemical characteristics of the 21 barley samples

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Field test wt, kg/hL	55.0	66.1	56.5	60.7	63.2	52.3	60.7	51.5	59.2	53.0	45.8	56.5	60.3	47.7	57.6	58.2	55.0	57.0	54.2	54.0	31.5
Clean test wt, kg/hL	55.3	66.8	56.7	61.1	62.8	53.4	61.7	52.3	59.6	53.4	46.0	58.4	61.5	52.8	57.1	58.6	56.1	58.8	55.3	56.0	35.1
Dockage, %	1.40	0.26	2.17	0.48	0.34	3.60	0.40	2.20	0.98	2.00	2.60	2.00	3.20	1.25	0.70	4.10	1.30	3.14	0.80	1.50	1.66
Moisture, % (Norwest)	13.9	12.2	14.1	14.0	14.4	13.1	14.3	15.2	13.5	13.3	17.9	12.6	10.2	12.8	13.5	16.0	15.0	14.4	11.7	13.6	16.2
DM, % (U of S)	86.7	88.9	86.4	84.9	87.8	88.0	87.7	87.2	88.2	88.4	84.8	88.9	89.8	88.4	87.7	87.7	86.5	87.8	89.0	88.3	85.1
DM, % (Norwest)	86.1	87.8	85.9	86.0	85.6	86.9	85.7	84.8	86.5	86.7	82.1	87.4	89.8	87.2	86.5	84.0	85.0	85.6	88.3	86.4	83.8
On a DM basis:																					
GE, kcal/kg	4395	4337	4412	4399	4424	4397	4403	4367	4362	4401	4399	4403	4414	4401	4347	4347	4362	4413	4424	4366	4462
DE, kcal/kg	3086	3097	3100	3200	3129	3029	3123	2673	2889	3060	2897	2996	2984	2703	2996	2985	2894	3003	3188	3291	2018
DE, kcal/kg (Northwest)	3710	3820	3740	3840	3800	3720	3720	3650	3730	3760	3660	3730	3730	3600	3740	3690	3730	3730	3770	3780	3500
CP, % (U of S)	12.82	8.78	13.22	12.35	13.10	11.88	12.87	11.91	11.71	12.92	13.25	13.36	12.98	13.03	12.39	14.44	9.70	15.43	13.69	12.28	12.29
CP, % (Norwest labs)	13.9	10.0	13.8	13.1	14.0	12.6	13.8	12.8	13.3	14.1	14.7	14.7	13.6	14.0	13.6	16.0	11.0	16.4	14.9	13.6	12.8
CP, % (Degussa)	13.81	10.32	14.07	13.09	14.22	13.23	14.32	12.60	12.86	14.49	14.94	15.14	13.92	14.74	12.93	16.02	11.12	16.39	15.24	13.69	13.79
ADF, % (U of S)	7.40	5.79	6.50	6.76	5.70	6.93	6.17	7.82	8.02	8.06	8.24	6.77	7.21	10.22	6.16	8.29	8.44	6.24	6.92	6.17	12.07
ADF, % (Norwest Labs)	7.0	4.8	6.4	4.5	5.2	6.8	6.8	8.2	6.6	6.1	8.1	6.5	6.5	9.2	6.4	7.4	6.7	6.5	5.8	5.7	11.4
NDF, % (U of S)	19.89	20.84	16.21	19.52	17.22	18.62	20.23	21.98	23.55	16.38	18.32	19.80	21.55	22.93	18.33	22.24	21.17	19.45	17.67	22.13	32.00
NDF, % (Norwest Labs)	25.1	22.2	21.9	25.1	26.8	24.6	25.7	28.7	25.2	22.7	27.0	26.3	25.0	28.8	25.7	28.9	28.0	28.5	24.4	24.9	35.1
EE, %	1.76	2.12	2.29	2.63	2.23	2.34	1.97	2.37	1.89	2.28	2.39	2.61	2.98	2.63	2.06	2.84	2.08	2.56	2.26	2.18	2.12
Ash, %	2.92	2.44	2.52	2.27	2.16	2.48	2.24	2.99	2.65	2.43	3.11	3.02	3.20	3.70	2.47	4.66	2.95	2.56	2.75	2.93	2.83
Lignin, %	0.93	1.41	0.86	1.21	1.47	1.21	1.05	1.10	0.99	1.37	1.37	1.56	1.19	1.20	1.27	1.22	1.23	1.16	1.68	0.86	2.67
Methionine, %	0.243	0.176	0.239	0.230	0.250	0.225	0.251	0.221	0.230	0.240	0.254	0.263	0.242	0.247	0.227	0.257	0.203	0.265	0.264	0.243	0.221
Methionine & cysteine, %	0.561	0.402	0.567	0.527	0.578	0.526	0.576	0.505	0.527	0.551	0.570	0.596	0.566	0.552	0.515	0.588	0.468	0.622	0.604	0.557	0.473
Lysine, %	0.529	0.376	0.507	0.486	0.488	0.497	0.531	0.509	0.497	0.537	0.539	0.554	0.521	0.565	0.514	0.533	0.449	0.562	0.560	0.503	0.569
Threonine, %	0.501	0.353	0.487	0.463	0.494	0.458	0.512	0.475	0.459	0.481	0.510	0.533	0.481	0.518	0.472	0.536	0.411	0.543	0.509	0.488	0.484